Isobutanol Compatability

What The Research Shows

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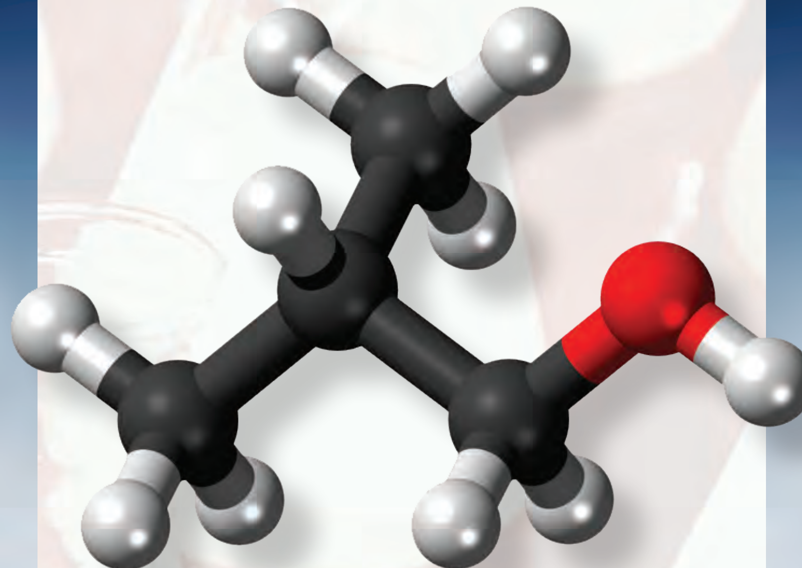

Three years ago, we provided *PEI Journal* readers with an overview of renewable isobutanol (also known as biobutanol) benefits for gasoline blending. That article described emerging technologies for converting abundant feedstocks such as corn, sugar cane and cellulosic materials into isobutanol. In addition, the article also suggested that isobutanol could contribute substantially to the transportation fuel future envisioned by the Renewable Fuel Standard (RFS) and California's Low Carbon Fuel Standard. The article also described isobutanol testing that was in progress, including a large-scale materials compatibility evaluation at Oak Ridge National Laboratory.

Now, the Oak Ridge research is completed, as are complementary tests and evaluations conducted by UL and Southwest Research Institute. And Butamax has published internal studies on isobutanol fuels' physical properties, material compatibility, drivability and environmental impact.

This article summarizes key test results that are pertinent to the petroleum equipment industry. Also included is a list of references for readers who seek more detailed information.

Oak Ridge National Laboratory in Tennessee has completed a large-scale materials compatibility evaluation on isobutanol.

Background

Renewable isobutanol is a four-carbon alcohol that delivers benefits similar to ethanol, plus attributes that overcome many of ethanol's limitations:

Compatibility. Sixteen percent isobutanol is equivalent to 10 percent ethanol in oxygen content and combustion stoichiometry, ensuring seamless compatibility with all E10-capable vehicles.

High Energy Density. Sixteen percent isobutanol offers the same fuel economy as 10 percent ethanol; vehicle fuel economy is maintained even when isobutanol is blended at increased concentrations.

High Renewable Energy Content. Isobutanol has a high renewable energy content and therefore provides an efficient pathway toward the RFS policy goals.

Water Stability. Isobutanol is stable in the presence of water. In addition to obvious product quality benefits, this introduces the option of transporting isobutanol fuel blends by pipeline—a potentially significant supply chain benefit.

Low Vapor Pressure. Isobutanol's attractive vapor pressure allows for improved refinery economics and better use of crude.

These benefits make isobutanol a promising solution for increasing the use of renewable transportation fuels. Much work remains to turn the possibilities into realities, but steps toward isobutanol commercialization already have begun. For example, ASTM, the international body that publishes technical standards on more than 13,000 items, has developed isobutanol fuel specifications. The National Marine Manufacturers Association also recently endorsed isobutanol as the preferred renewable fuel for recreational watercraft.

Compatibility and Physical Properties

Elastomer Compatibility. Figures 1a and 1b show the experimental apparatus used in the Oak Ridge materials compatibility tests. Elastomers chosen for the Oak Ridge studies were representative of the seals, o-rings and conduits in vehicle fuel systems, fuel storage and dispensing systems, and tanker truck hoses, as well as other materials likely to experience incidental fuel contact.

Figure 1a

The specimens of fluorocarbon, fluorosilicone, nitrile rubber (NBR), polyurethane, neoprene, styrene butadiene rubber (SBR) and silicone rubber were exposed to ASTM Reference Fuel C, ethanol and isobutanol fuel blends for four weeks at 60°C. Fuel C, a 50-50 mixture of isooctane and toluene, has been the ASTM fuel most often associated with materials testing since 1980.

After being measured for weight, hardness, swelling and glass transition temperatures, the specimens were dried for 20 hours at 60°C and then remeasured.

Test results indicate the material compatibility performance and characteristics of isobutanol blends are similar to those of comparable ethanol blends.

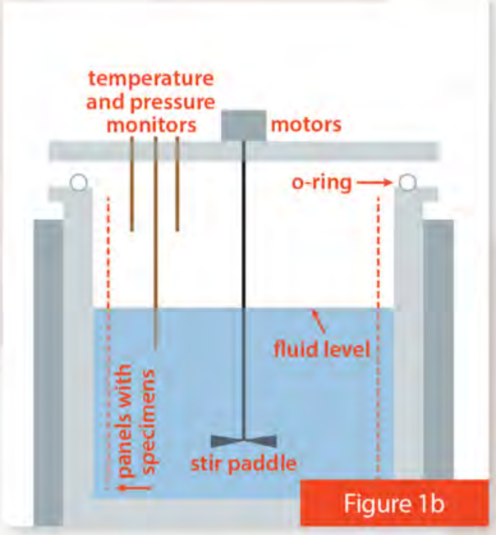

Figure 1b

All elastomer materials experience volume expansion and softening when wetted by the test fuels, and ethanol produces slightly higher swell than the oxygen equivalent level of isobutanol. Figure 2 presents examples of the experimental swelling results for various specimens. Bu16 is shown between the two comparison fuels (Fuel C and E10). Figure 3 presents hardness changes for several other samples.

Plastics and Resins Compatibility. Oak Ridge tested plastics and resins typically in vehicle fuel systems, fiberglass

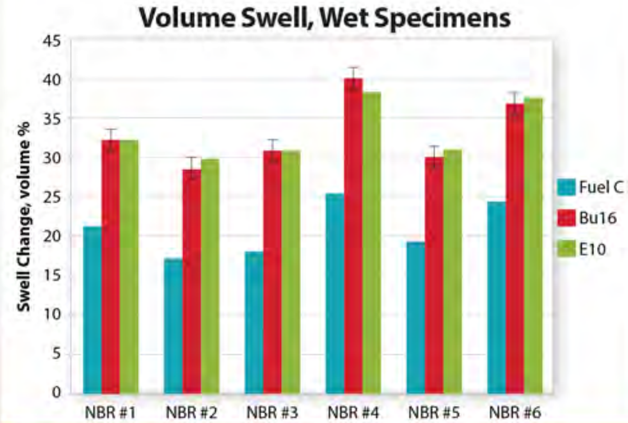

Figure 2. **NBR Elastomers Comparisons of Wet Specimens**

underground storage tanks (USTs) and vehicle fueling infrastructure using the procedures described.

The evaluation of 16 plastics and resins measured changes in weight, volume and hardness, as well as tensile, flexural and compressive properties and changes in glass transition temperatures. Results confirm that most materials are compatible with isobutanol fuels for normal applications and conditions. In addition, exposure to isobutanol blends produces changes similar to those for comparable ethanol blends.

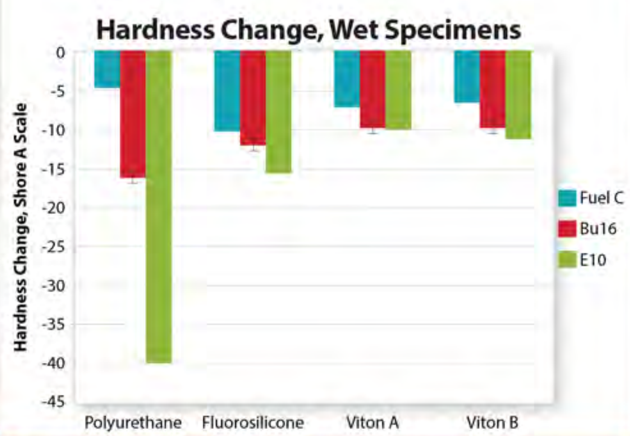

Figure 3. **Polyurethane and Fluoroelastomers, Wet Specimens**

Metals Compatibility. Metals typically encountered in vehicle fuel systems and fueling equipment—including brass, bronze, nickel-plated aluminum and steel, chromium-plated brass and steel, galvanized steel and terneplate—also were tested for compatibility. In addition to fully plated metals, separate coupons also were prepared with part of the plating removed to expose the substrate.

The metal corrosion potential of fuel blends largely is a function of conductivity; the greater the conductivity, the greater the corrosion potential. Figure 4 shows that isobutanol's conductivity is consistently low. Isobutanol blends produce negligible metal corrosion rates even under severe accelerated testing conditions.

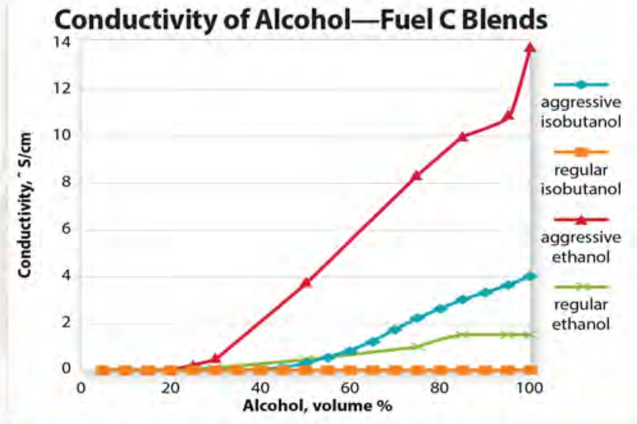

Figure 4. **Conductivity of Alcohol Blends in Fuel C**

Physical Properties. Reliable engineering assessments of fuels require accurate data on the fuels' physical properties. Butamax's physical property measurements for isobutanol blends include data on volatility, viscosity, lubricity, electrical conductivity and the behavior of isobutanol blends in the presence of water.

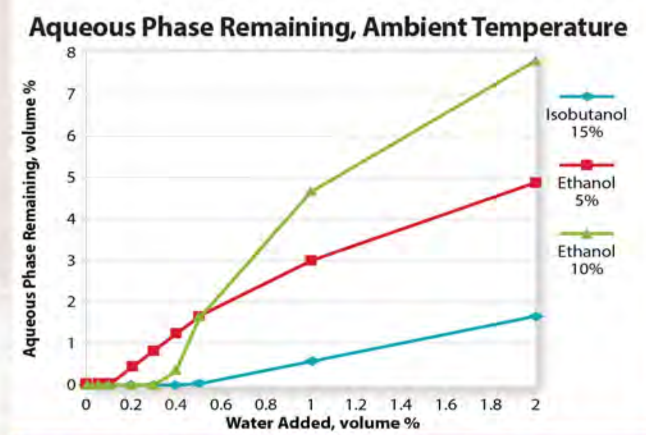

Figure 5. **Effects of Adding Water to Fuel Blends**

Three issues are particularly important when considering the interaction of water with alcohol-gasoline blends:

1. the maximum amount of water the blend will absorb before aqueous phase separation occurs;
2. the amount of aqueous phase that forms after the maximum amount of water is added to the blend; and
3. the composition of the aqueous phase, i.e., how much alcohol in the gasoline will migrate to the aqueous phase.

Figure 5 shows the typical behavior of E5, E10 and 15 percent isobutanol gasoline in the presence of water. As shown in the graph, E5 begins phase separation at about 0.2 percent added water, E10 at about 0.4 percent, and 15 percent isobutanol at about 0.6 percent.

With continued addition of water to the two ethanol blends, the aqueous phase volume exceeds that of the added water, indicating significant levels of ethanol have moved into the aqueous phase. As shown in Figure 6,

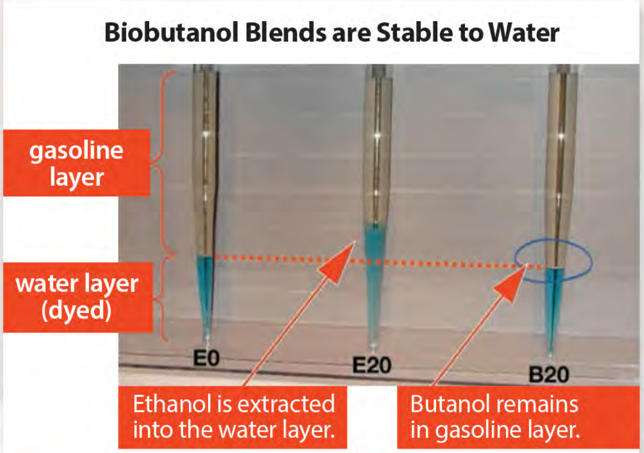

Figure 6. **Demonstration of the Effects of Adding Water to Fuel Blends**

the isobutanol blend behaves more like pure gasoline in this situation.

Summary

Extensive experimental data exists on the compatibility of isobutanol blended gasoline with elastomers, plastics, resins and metals used in vehicles, fuel storage and dispensing systems. When considered with the broad range of materials and conditions tested, isobutanol fuel blends compare favorably to and represent a viable alternative to ethanol.

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To Learn More

The following references are a partial compilation of recent research, reports, publications and findings that relate to isobutanol's physical properties, compatibility and use.

1. Koch, W. and Baustian, J., *Isobutanol: Biofuel of the Future,* PEI Journal pg. 34, 4th Quarter, 2012.
2. *Compatibility Study for Plastic, Elastomeric and Metallic Fueling Infrastructure Materials Exposed to Aggressive Formulations of Isobutanol Blended-Gasolines,* Kass, M. et al, Oak Ridge National Laboratory, Report ORNL/TM-2013/243, August 2013. http://info.ornl.gov/sites/publications/Files/Pub44488.pdf
3. Kass, M., Theiss, T., Pawel, S., Baustian, J., Wolf, L., Koch, W., Janke, C., *Compatibility Assessment of Elastomer Materials to Test Fuels Representing Gasoline Blends Containing Ethanol and Isobutanol,* SAE Int. J. Fuels Lubr. 7(2):2014, doi:10.4271/2014-01-1462.
4. *Compatibility Assessment of Plastic Infrastructure Materials to Test Fuels Representing Gasoline Blends Containing Ethanol and Isobutanol,* Kass, M., Janke, C., Theiss, T., Baustian, J., Wolf, L., Koch, W., SAE Int. J. Fuels Lubr. 7(2):2015, doi:10.4271/2014-01-1465.
5. *Compatibility Assessment of Plastic Infrastructure Materials with Test Fuels Representing E10 and iBu16,* Kass, M., Janke, C., Theiss, T., Baustian, J., Wolf, L., Koch, W., SAE Int. J. Fuels Lubr. 8(1):2015, doi:10.4271/2015-01-0894.
6. Internal reports available from Butamax website (www.butamax.com):
   a. *Compatibility assessment of elastomer materials to test fuels containing ethanol and isobutanol*

UL LISTING

Underwriters Laboratories (UL) has advised that 16 percent isobutanol-gasoline blends are acceptable in equipment certified to UL's Subject 87A. This gives 16 percent isobutanol blends the same commercialization path as E15. UL is continuing to investigate isobutanol's compatibility with legacy dispensing equipment.

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   b. *Compatibility assessment of plastics and resins to test fuels containing ethanol and isobutanol*
   c. *Compatibility assessment of metals to test fuels containing ethanol and isobutanol*
   d. *Physical properties of isobutanol-gasoline blends*
   e. *Permeation emissions in vehicle fuel systems using isobutanol blends*
   f. *Driveability of isobutanol-gasoline blends*
   g. *Fleet experience with isobutanol-gasoline blends*
   h. *Additive response and intake valve deposit control of isobutanol-gasoline blends*
7. ASTM Standard D7862, 2013, "*Standard Specification for Butanol for Blending with Gasoline for Use as Automotive Spark Ignition Fuel,*" ASTM International, www.astm.org.
8. "*Recreational Boating Industry Turning to Biobutanol as Alternative Biofuel,*" National Marine Manufacturers Association, 17 June 2014, http://www.nmma.org/press/pressreleaselibrary/pressrelease.aspx?id=19947
9. Society of Automotive Engineers, *Gasoline, Alcohol, and Diesel Fuel Surrogates for Materials Testing,* SAE J1681, issued September 1993, revised January 2000-01.
10. UL guidance on equipment listings:
   a. Biofuels: http://industries.ul.com/blog/alternative-fuels
   b. Isobutanol: http://industries.ul.com/wp-content/uploads/sites/2/2015/01/Isobutanol.pdf